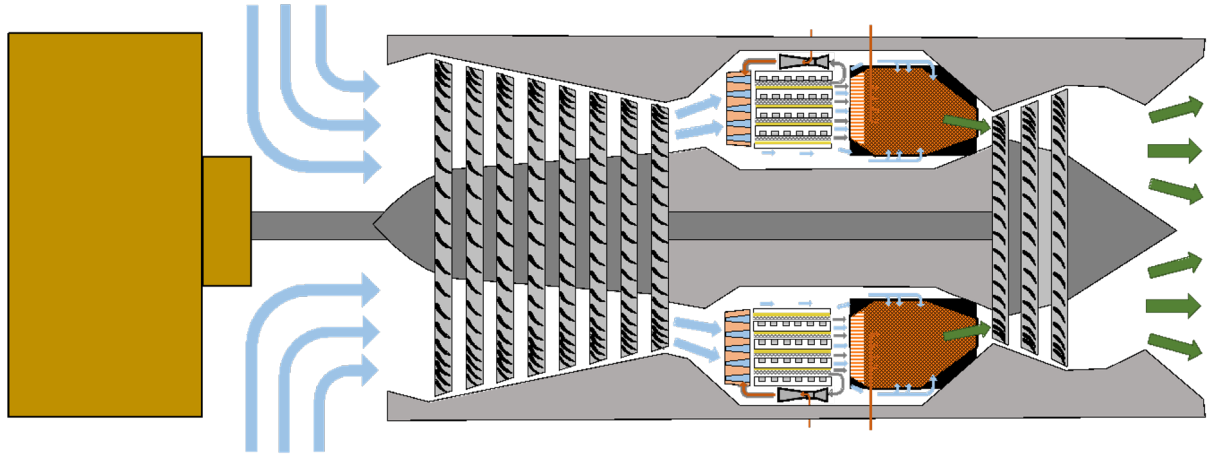
Hybrid SOFC/Turbogenerator for Aircraft

Christopher Cadou, University of Maryland

Range Extenders for Electric Aviation with Low Carbon and High Efficiency (REEACH)

Project Vision

Slash fuel consumption and emissions by developing a high-performance reformer/fuel cell element featuring SOA fuel cell materials and novel weight-saving architectures that can be integrated into a gas turbine's flow path to exploit turbine/fuel cell synergies.



REEACH / ASCEND / CABLES
Annual Program Review Meeting
June 28-30, 2022

Brief REEACH Project Overview

Team member	Location	Role in project
Christopher Cadou	University of Maryland	PI; Overall system modeling, pressurized ATR/SOFC testing
Eric Wachsman	University of Maryland	High power density fuel cell development
Greg Jackson	Colorado School of Mines	Co-I; ATR/SOFC design and modeling
Robert Braun	Colorado School of Mines	ATR/SOFC design and modeling; Technoeconomic analysis
Tyrone Vincent	Colorado School of Mines	ATR/SOFC controls
Charles Lents	Raytheon Technology Research Center	Large-scale ATR/SOFC testing, turbomachinery modeling and design, business development


Christopher Cadou


Eric Wachsman


Greg Jackson


Robert Braun


Tyrone Vincent


Charles Lents

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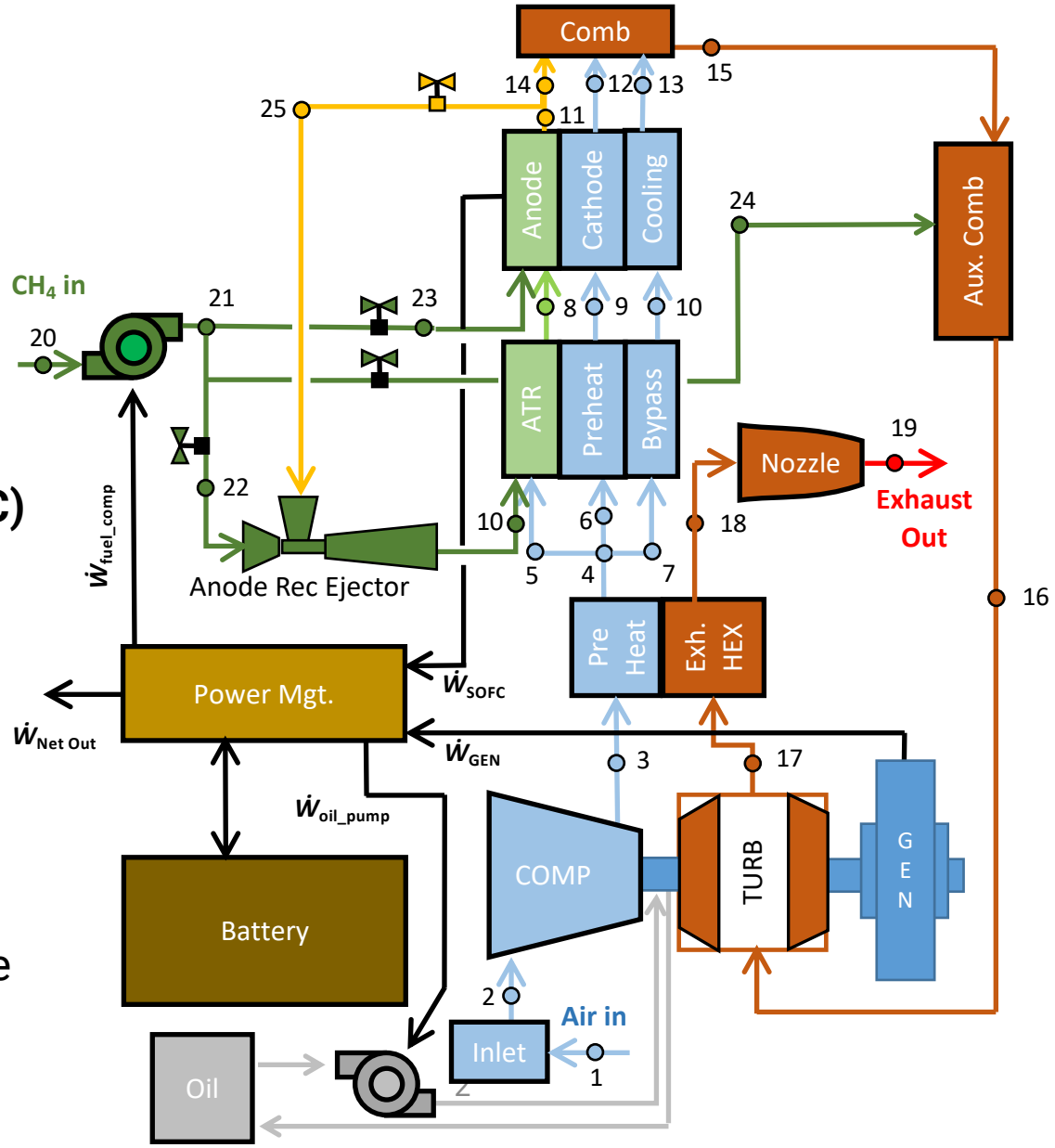
Innovation

Project Objectives

- **Key component-level innovations**
  - Highly integrated SOFC/reformer/heat exchanger
  - Low-mass interconnect design →50% lower weight
- **Novel aspects compared to SOA**
  - High-power SOFCs offer >2 W/cm^2 at < 650°C (SOA ~1 W/cm^2)
  - Proprietary stack design to lower interconnect mass
  - Compliant seals to permit rapid heating
- **Target performance (OPR=15, 13 MW w/ 1.8 MW$_{elec}$ SOFC)**
  - Spec. Energy = $\mathbf{4.5kWhr/kg}$ $(\geq 3\text{kWhr/kg})$
  - Spec. Power = $\mathbf{3.0kW/kg}$ $(\geq 0.75\text{kW/kg})$
  - Fuel Cost = $\mathbf{\$0.14/kWhr}$ $(\leq \$0.15\text{/kWhr})$
  - Capital Cost = $\mathbf{\$715/kW}$ $(< \$1000\text{/kW})$
  - **Reformer/ATR Spec. Power $> \mathbf{1.5kW/kg}$**
- **Tools being developed to support project**
  - Analytical and NPSS system models
  - High-fidelity MIEC stack models for high-P performance
  - Pressurized SOFC test rig



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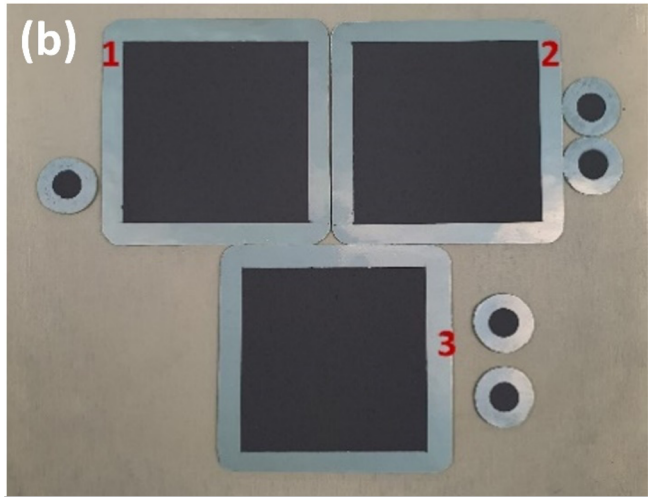
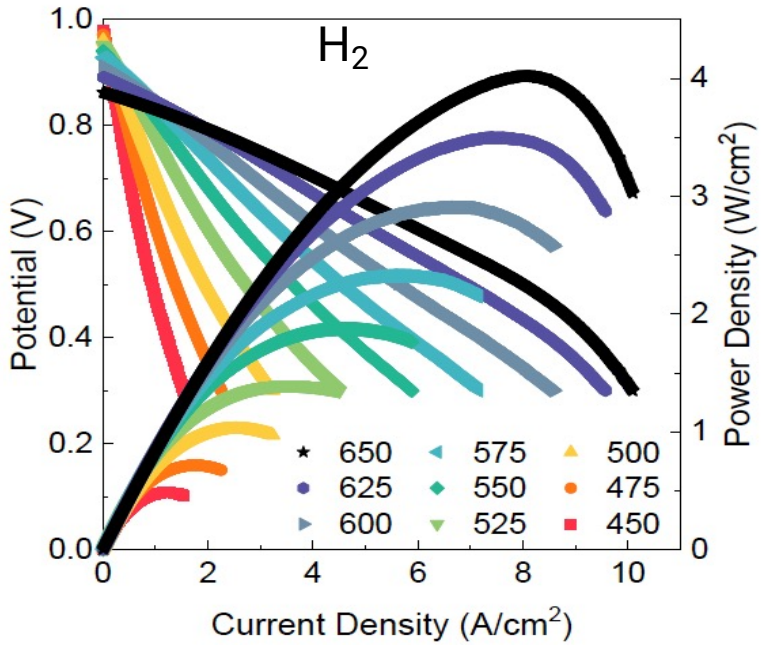
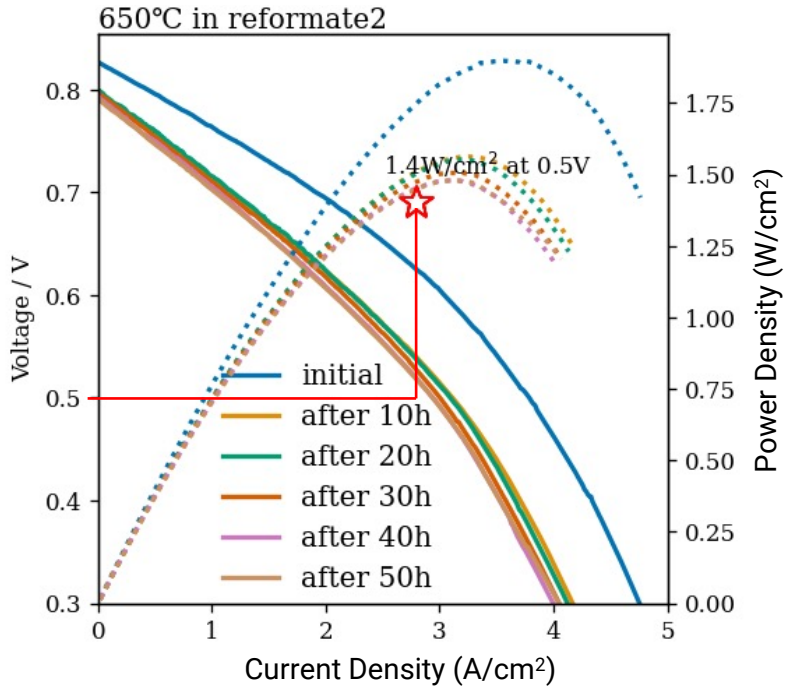
High Power Cell Development (25 cm² Cell)

- Developed repeatable process for button and larger (25 cm²) format cells
  - All made by same tape casting, laminating, sintering, & spray coating processes
  - 25 cm² cells exceed flatness of commercial cells
- Button cells achieved 4 W/cm² in H_2 and exceed performance milestones for reformate fuel
- 25 cm² cell testing limited by test fixture capability to operate at high currents, modifications to fixture in process





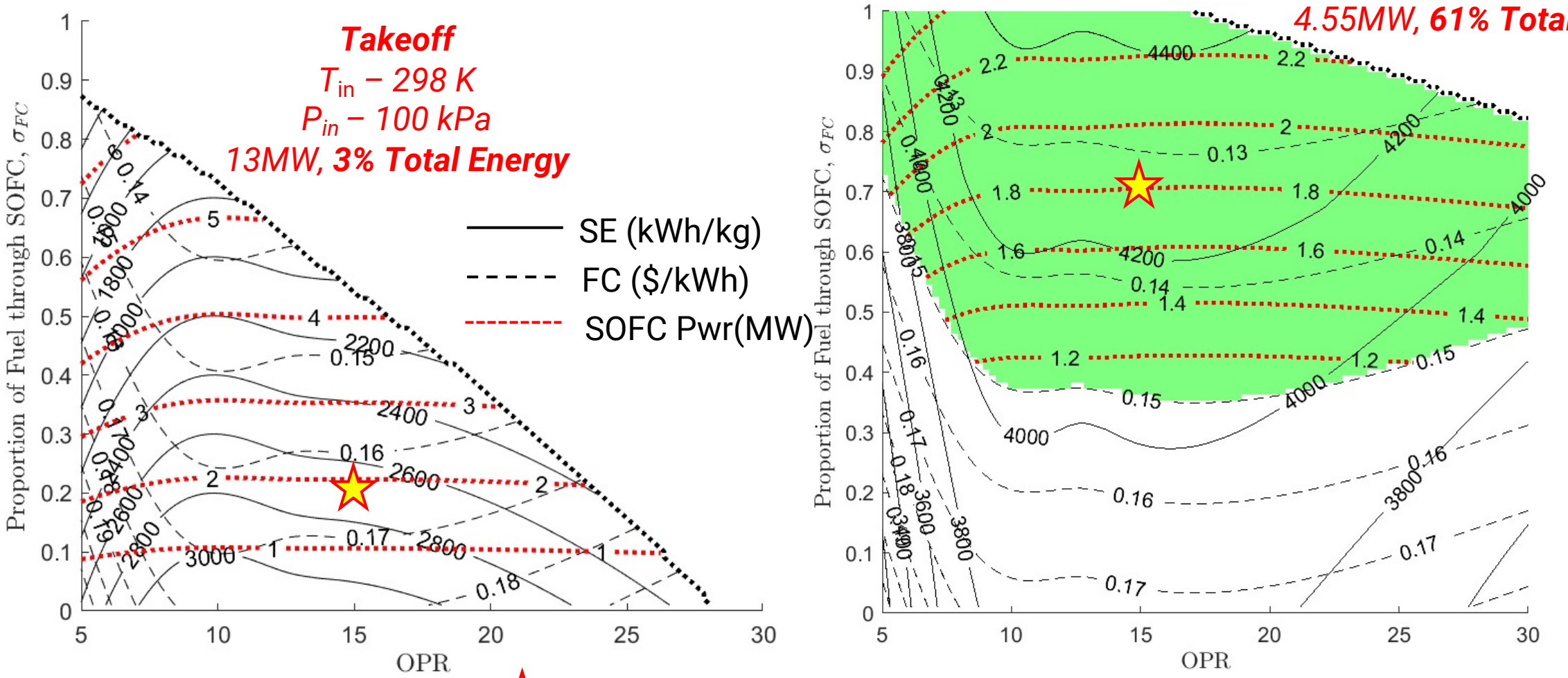


System Analysis

- Identify configurations that satisfy REEACH program metrics

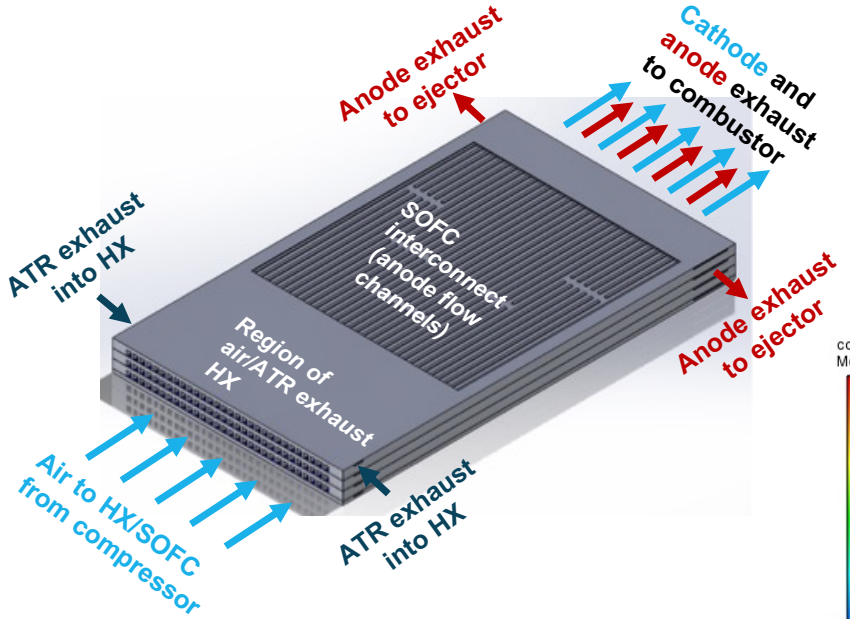
Takeoff
T_{in} – 298 K
P_{in} – 100 kPa
13MW, ***3% Total Energy***

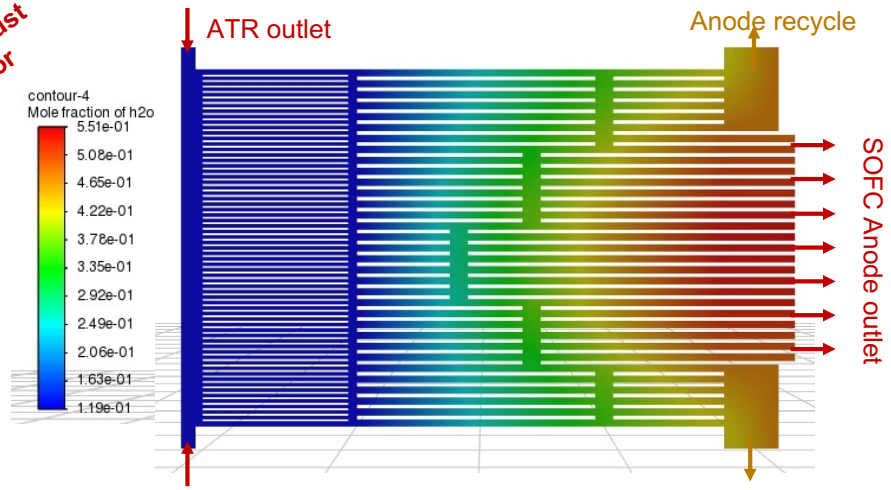
35,000 ft. Cruise
T_{in} – 219 K, P_{in} – 24 kPa
4.55MW, ***61% Total Energy***

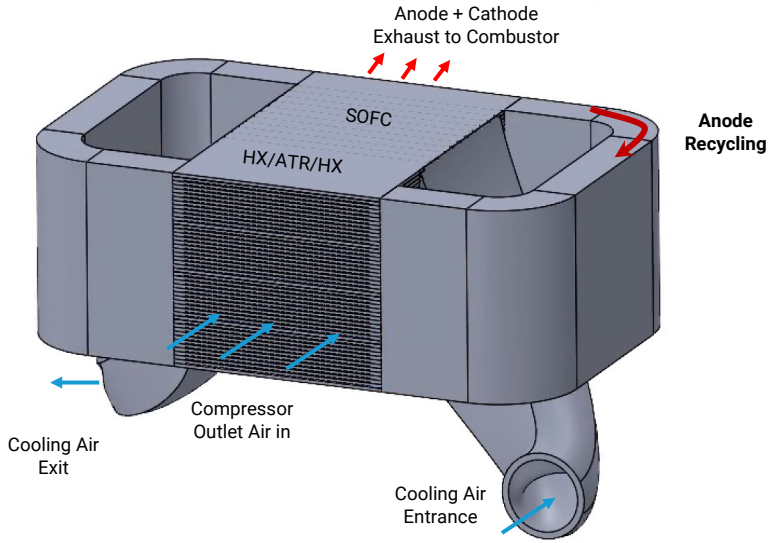


Integration of SOFC/Autothermal Reformer/Heat Exchanger

- *High-power density electrochemical cells that light off with inlet temperatures < 600°C*
- *Low-mass interconnect and single-body integration of upstream fuel processing and heat exchange*
- *Stack-level models for design of reliable anode flow splits to support product H_2O recycling*
- *Compliant seals for good thermal response and high-power density performance > 1.6 kW_{elec}/kg*





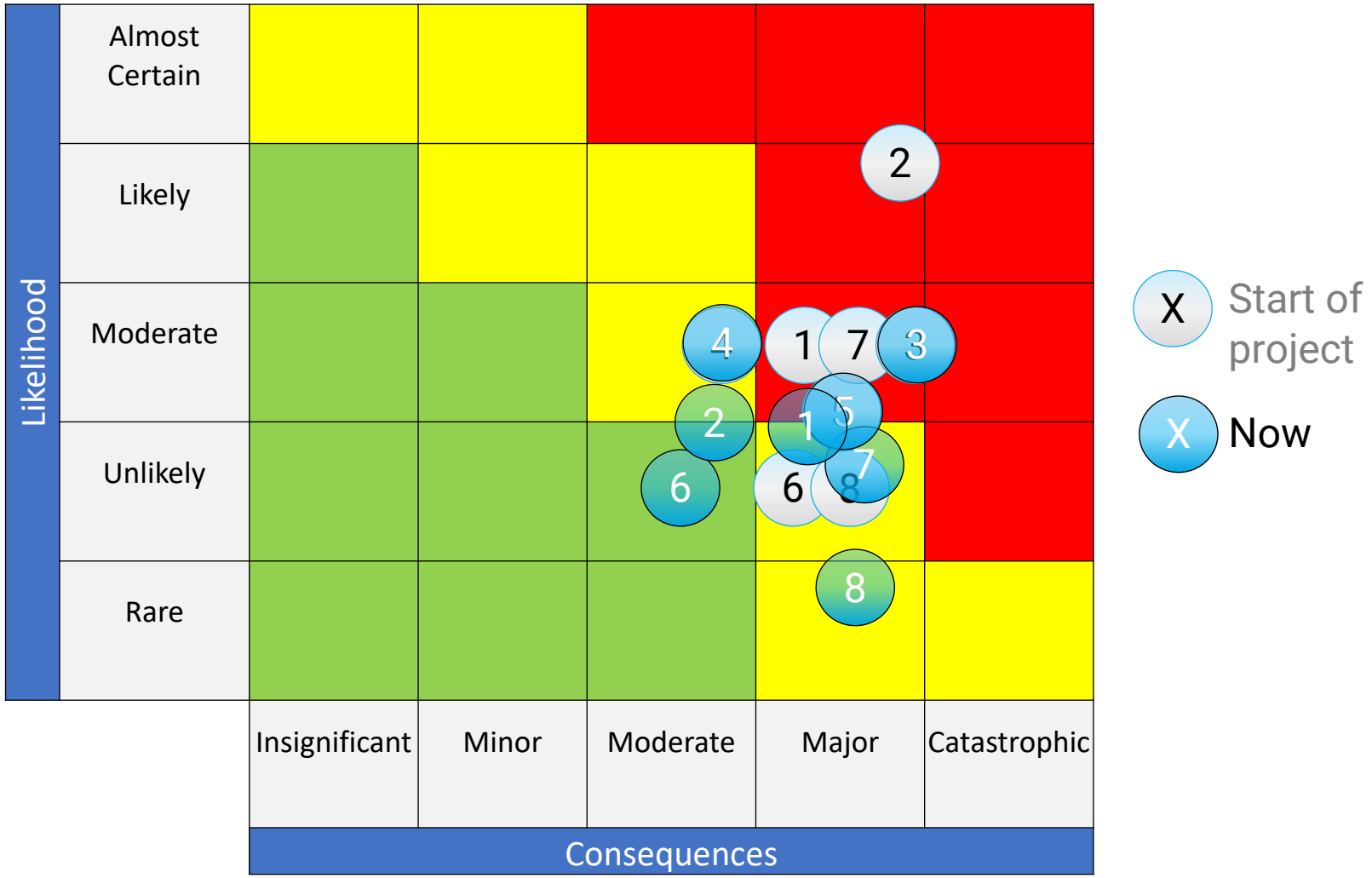


Task Outline & Technical Objectives

- *Develop high power SOFC 25cm^2 cells and demonstrate a pathway to 100cm^2 high power redox tolerant cells at ≤650°C*
  - *Achieved >1.4W/cm^2 @ 0.5V on reformate in GDC button cells for 50 hrs*
  - *Achieved >0.9W/cm^2 @ 0.75V in 25cm^2 planar GDC cells*
- *Demonstrate a 1.0 kW$_e$ integrated SOFC/ATR using COTS cells*
  - *Specific power > 1.2 kW$_e$/kg at 0.75V/cell*
  - *p ≤ 15 bar*
  - *T ≤ 650 ℃*
  - *Degradation rate < 2%/hr over 6 hrs.*

Risk Update

#	Risk
1	ATR/SOFC Integration
2	High power density SOFC
3	Inadequate anode exhaust/thermal control
4	Excessive anode leakage
5	Component failure due to CTE mismatch
6	ATR/SOFC failure debris damages turbomachines
7	Manufacturers perceive concept as too risky
8	Capital and maintenance costs too high



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Technology to Market

Life Cycle Cost Sensitivity Analysis Results

	LCC ($k)	% Δ
Base	57,244	
10% reduction in OEM cost	56,314	1.6%
10% reduction in weight	57,057	0.3%
10% reduction in yearly maintenance cost	57,155	0.2%
2% increase in efficiency	56,341	1.6%

Potential Applications

	SA Parallel	SA Aux Prop	Regional
Rating	2000 kW	2 X 3600 kW	1500 kW
PD & Eff	2 kW/kg	1.7 kW/kg	3 kW/kg
Eff	60%	64%	60%
FB benefit	5%	6-14%	15%

SA – single aisle, PD – power density, FB – fuel burn

Commercialization

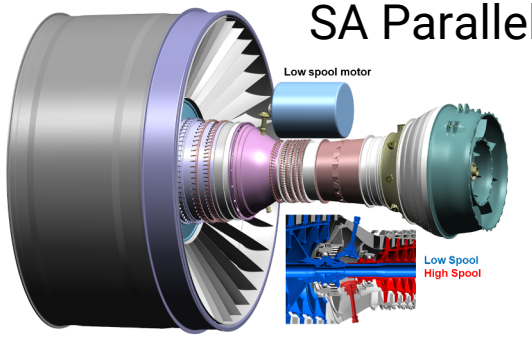
ALCHEMITY

Manufacturing SOFCs and SOECs.

Raytheon Technologies

Integration and path to market

SA Parallel



SA Aux Propulsor

Regional Parallel

AAM

Image Credit: Electra.aero

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Needs and Potential Partnerships

- *Current Needs*
  - *Low-mass interconnect fabrication with robust SOFC-compatible alloys*
  - *Reliable ejector design for high-T anode exhaust recycling*
  - *NPSS community of practice*
- *Post completion needs*
  - *Additional market opportunities*
- *Capabilities*
  - *Stack and system modeling*
  - *NPSS expertise*
  - *Pressurized SOFC testing*

Q & A

https://arpa-e.energy.gov